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Influence of thermal fatigue on degradation behaviour in surficial layers of selected glass industry parts

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Abstract

The given paper deals with evaluation of the boundary state of degradation of materials, which are exposed to high temperature variation. A significant operating wear appears at these materials. The work results from description of possible boundary states which are not meeting requirements for the final product and they are also connected with the root cause of the wear origin. The experiment was connected with evaluation of prepared microstructures of initial and operating material in that connection with fractography. Based on the fact that chemical analyse of this material shows inconsistency in chemical composition in comparison with declared material, the attention was given to influence of additive and alloying components. The study of undesirable phases, which occur in the microstructure, proves the inappropriate choice of the initial material. On the basis of experiments and obtained results, recommendations, which might be used for prediction of appearance of boundary states of microstructure during operation, were proposed. As long as the chemical composition is not fulfilled, a presence of greater amount of non-metallic elements (sulphur, oxygen, nitrogen, etc.) is observed. These elements are bound with chromium, molybdenum, manganese, nickel and other alloying elements, with which create chemical compounds (in metallurgy, they are designated as inter-metallic or intermediary phases).

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1. Introduction

The paper deals with the given task concerning boundary states of selected corrosion resistant steels which are exposed conditions of thermo-mechanical loading. The experimental and computing modelling have to arise from monitoring of degradation processes, which appears on the surface of exposed material under the real and predetermined working conditions. Due to the reason, that it deals with the corrosion resistant steel, which is used for glass moulds or for pre-moulds, an attention was given to the material, which the particular components were made of. The investigation deals with the materials designated as Dominial ZF2 in such a state as it is used in glass industry without any surface treatment. Based on practice and bibliographic search, the chrome based coating was applied on the introduced material during the process of investigation. This material was exposed to the thermal loading and continuously evaluated from the point of view of material properties as well as their fracture behavior.

Inputs for the given investigation process are:

- Material for the glass part – without and with coating (initial material for glass mould)
- Geometry for construction part – glass mould, pre-mould
- Operating temperature, various time load simulations at 850 °C
- Maximal pressure on the surface of mechanically loaded materials
- Operating conditions of the glass processing – time interval of the loading, (mechanical, thermal loading)
- Influence of the surface treatment (on material designated as Dominial ZF-2, l)
- Coating thickness (1.5 and 3 μm)
- Material properties of coating

2. Course of experimental modelling

Evaluation of Dominial ZF-2 was performed from the point of view of structure, micropurity and chemical composition. It dealt with tool steel designated as 1.2782 (DIN X16CrNiSi25-20) under trade name DOMINIAL ZF2 ESU. The given material belongs to high alloyed steels with austenitic structure, where high thermal stability and corrosion resistance is declared and moreover, in relation to this material, there is also the assumption of maintained surface quality of casted glass, which is with it in interaction.

Samples of above mentioned material (called in the text Dominial ZF-2) were made for static tensile test. Some of the samples and selected areas of the glass moulds, which were cut into smaller parts, were coated by PVD method. Coating on basis of CrAlN with thickness of 1.5 μm and ca. 3.0 μm was deposited before the thermal loading. Heating of prepared material was carried out in the oven to the temperature close to its operating loading and it was ca. 850 °C (exposure time: 4, 6 and 12 hours). After the each one thermal exposure, the material was always cooled down fast in the water of 18 °C. The static tensile test of samples, before and after thermal loading, was carried out in order to determine changes in ultimate strength. Given fractures were subsequently examined in the fractographic way and it was immediately after the static tensile test (observation was performed from the point of view of macro and micro). Micropurity and changes of microstructure in the area of fracture were studied for all samples. Monitoring of changes in chemical composition was supplemented by planar and line element analyses for the surface and under surface layer of examined materials. Hardness tests in the area of fracture were selected to prove if improved hardness of tested material occurred by influence of plastic deformation or thermal loading. On the basis of the given results, input algorithms for computing modelling from the point of view of thermo-deformation states on the surface of glass plate were proposed.

3. Experimental background

1. The static tensile test proved that the longer time interval of material thermal loading led to decrease of the ultimate strength. The influence of the various thickness of coating on the Dominial ZF-2 was not observed.
2. After the static tensile test, the samples for observation were prepared in a metallographic way and subsequently, these prepared microstructures were observed in longitudinal direction (in the direction perpendicular to the

fracture area). Dominial ZF2 had austenitic structure, with numerous number of twins and with presence of chrome carbides, which had influence on characteristics of the rupture or fracture.

3. The original microstructure, shown in Fig. 1, is in the close proximity of the fracture area of material without thermal loading.

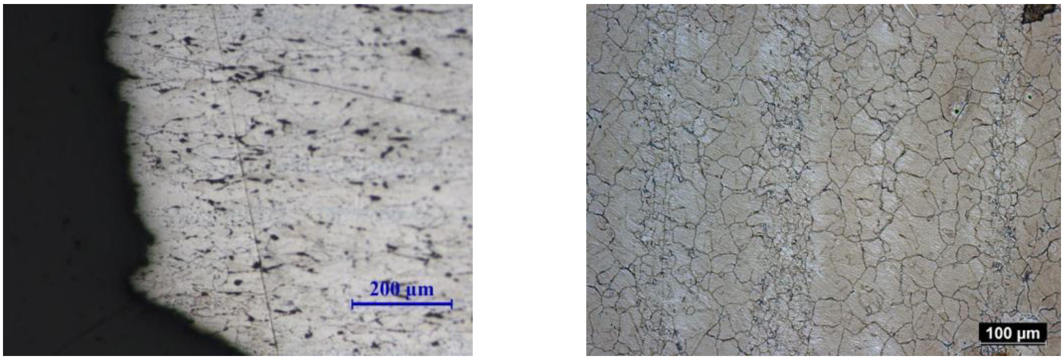

Fig. 1. Dominal ZF2 – Microstructure in the area of the fracture.

4. Microstructure after thermal loading

After thermal loading, the austenitic steel is characteristic by containing distinctive lines of carbides. Polyform grains in the proximity of the fracture are plastically deformed and elongated in the direction of the loading. In the Fig. 2, line structure can be seen in carbide arrangement as well as in elongation and deformation of austenitic grains. Furthermore, the coating is ruptured under the fracture area and it can be seen in the Fig. 3.

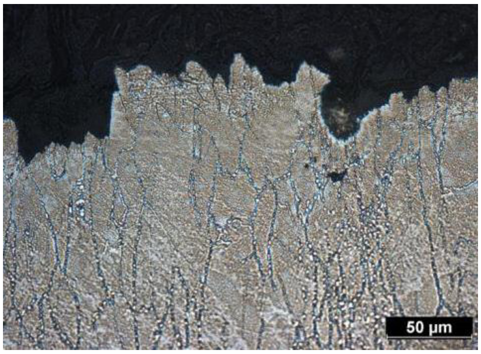

Fig. 2. Dominial ZF-2 – microstructure in the proximity of the fracture.

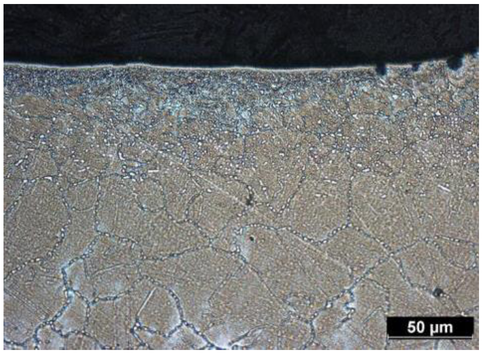

Fig. 3. Coated Dominial ZF-2 – material in the proximity of the fracture.

5. Fractography

Fracture areas are significantly influenced by arrangement of carbide phases and quality of surface. Initiation of cracks occurs in the surface layers during operation and there is also the formation of initialisation centres of cracks which are uncontrolled in corrosion environment at cyclic high temperatures. After static tensile test, fractographic evaluation of these corrosion resistant steels (and thermal loading) is useful for evaluation of susceptibility of those steels against failures [1–3]. The fracture obtained by static tensile test was always observed in the thinnest place of sample. In the Fig. 4, there is the fracture area of the initial material and typical fracture area with CrAlN coating is shown in the Fig. 5 and the given figures were obtained after the 2 hours of loading (Figs. 6, 7).

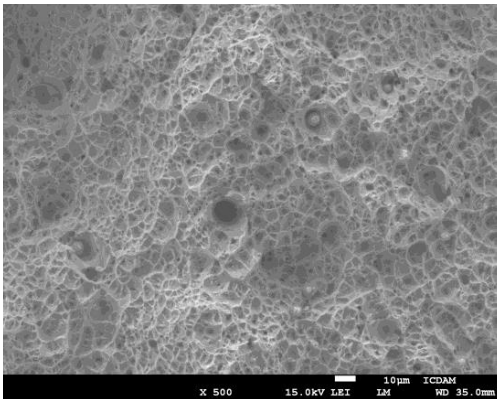

Fig. 4. Fracture after 12 hours of thermal exposure.

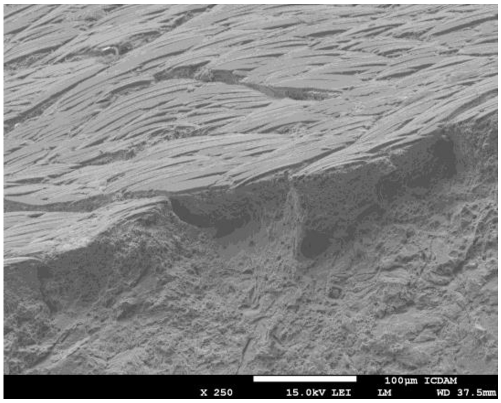

Fig. 5. Edge area of the fracture with coating.

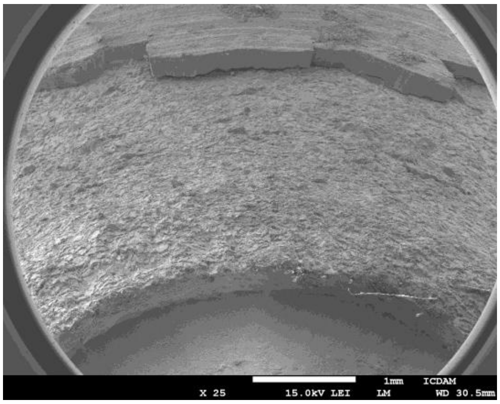

Fig. 6. Non-coated Dominial ZF-2 with oxide layer after long time interval of thermal loading.

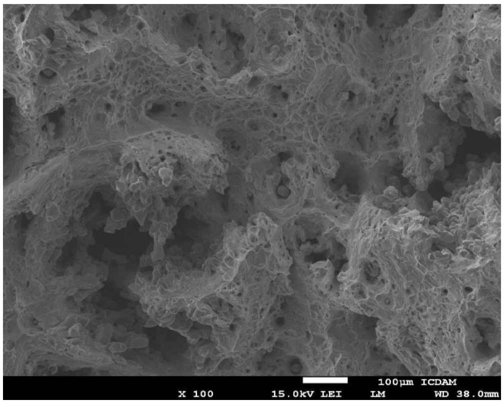

Fig. 7. Fracture area of Dominial ZF-2 without coating with oxide layer.

6. Approach to computing modelling

Nowadays, the computing modelling belongs to the advanced methods for investigation of the behaviour of the materials used for specific purposes. The proposal of any computational modelling should be based on the input parameters and data, which are obtained from experiments, directly in operation.

In relation to our investigation, the computational models for glass mould without coating with oxide layer and mechanical-thermal deformation of glass mould with coating can be seen in the Figs. 8 and 9 and temperature, pressure and loading time on the functional surface of the metal moulds for glass processing represent the substantial parameters in this case.

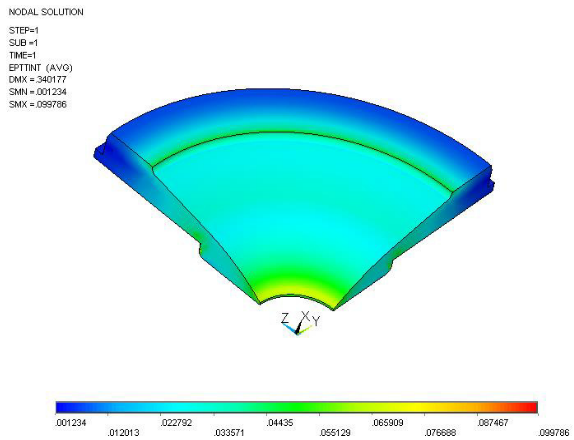

Fig. 8. Glass mould without coating with oxide layer.

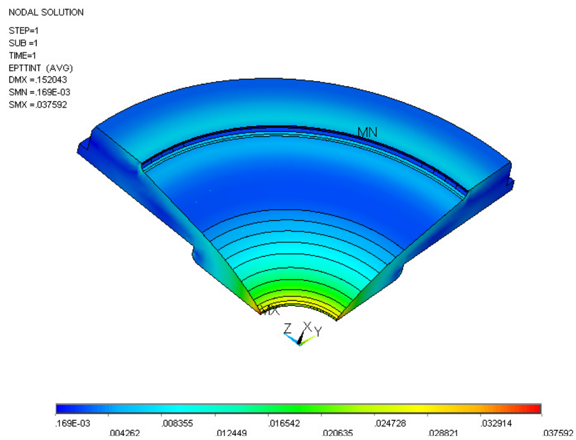

Fig. 9. Glass mould with coating – Mechanical-thermal deformation.

7. Proposal of input algorithms for the computing modelling

The description of behaviour of selected materials either with coating or without coating requests obtaining of input parameters directly from production and on the basis of the given results, it is necessary to carry out the algorithmisation of the processes. In the most cases, it deals with the technique of continual measurement by direct quantification of changes of material properties and it is closely connected with the interaction of the investigated materials.

Monitoring of all running changes and their continual evaluation in real time is not technically viable or even possible, mainly due to the presence of hot molten glass. In relation to predictions of the rupture, following algorithms needed for computing modelling of complex degradation process of the wear are not always available. This fact is connected with these algorithms:

- Algorithms of loading of functional surface, which is needed for measurement of loading forces acting during the operation on the mould surface in real time
- Algorithms for generation of surface topology of the glass moulds, which is obtained from measurement of continual changes of the surface geometry and decrease of the initial material or applied coating in the real time
- Algorithms which would react on continual changes of material in surface layers
- Algorithms describing changes of elastic and endurance characteristic of the initial material vs. coating
- Algorithms for determination and assessment of residual stress changes caused by production process and its history of technology (thermal processing, grinding, polishing)
- Algorithms for continual deformation determination, transformation and tension caused by utilisation of part
- Algorithms of changes in mould geometry while these changes are caused by stress-strain states which are the results of complex loading forces on the surface
- Algorithms of thermal gradients in perpendicular direction from surface to the initial material
- Algorithms describing individual processes of the wear, such as adhesion, corrosion, vibration, fatigue rupture or even their combinations
- Algorithms determining time and accuracy of the boundary states related to the rupture of parts
- Algorithms of construction unit vibration with the reference to the given changes in the operation etc.

8. Conclusion

On the basis of the obtained results relating to specified experimental procedures, using the predetermined methods of observation as well as investigation, it can be concluded that static tensile test proved that the longer time interval of material thermal loading led to decrease of the ultimate strength. The influence of the various thickness of coating on the Dominial ZF-2 was not observed Furthermore, Dominial ZF2 had austenitic structure, with numerous number of twins and with presence of chrome carbides, which had influence on characteristics of the rupture or fracture. Taking the experimental investigation into account, the computing modelling was used for the creation of the specific algorithms which can be useful and contribution for enhancement and accuracy of prediction from the aspect the complex degradation processes in the material used in glass industry. The process of the algoritmisation is going to be the further process of investigation.

Acknowledgement

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